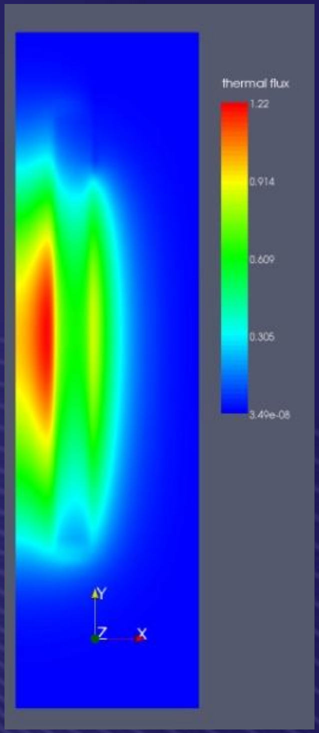
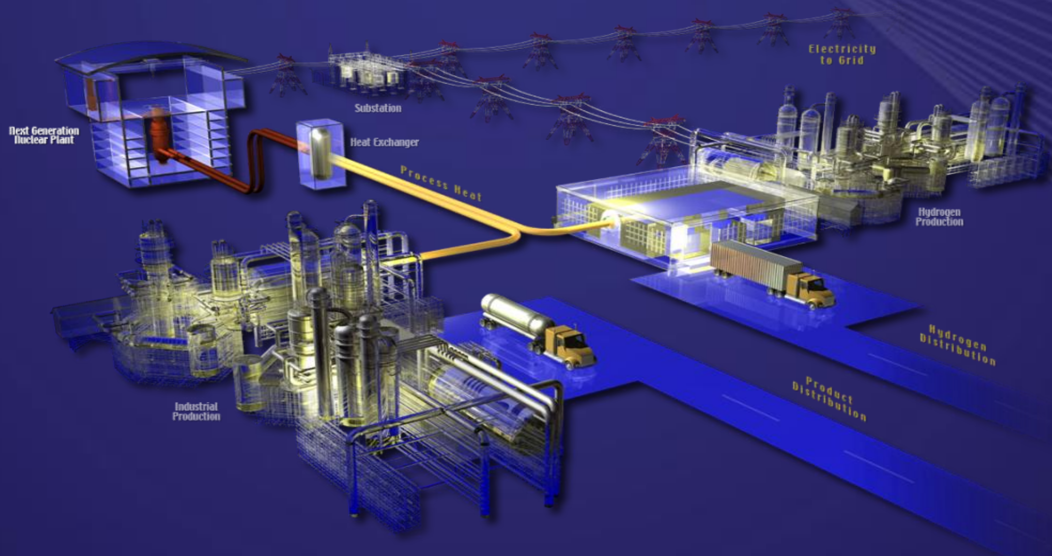
Nuclear Energy University Programs

NGNP Methods Development

Hans Gougar

August 10, 2011



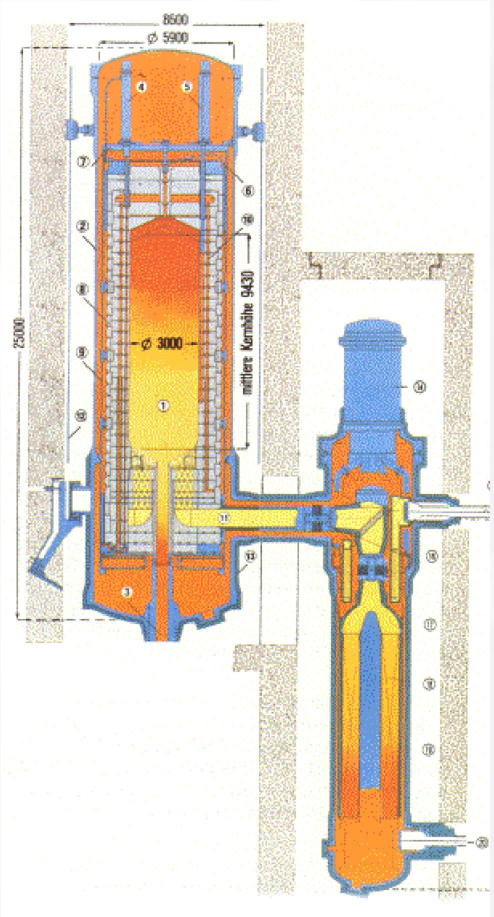


Next Generation Nuclear Plant

- The NGNP Project is part of the Advanced Reactor Concepts development effort
- NGNP specifically seeks to expand the use of nuclear energy beyond electricity generation (high temperature process heat and hydrogen for industrial applications)
- The NGNP R&D Program is engaged in the qualification of high temperature reactor fuel, materials (graphite and alloys), and design and analysis methods
- The VHTR Technology Development Office is the R&D arm of the NGNP Project and is based at the INL. Team members include: ORNL, ANL, and university partners.

High Temperature Gas-Cooled Reactors (HTGR or VHTR)

- The VHTR is a helium-cooled, graphite moderated reactor with a core outlet temperature between 750 and 850°C with a long-term goal of achieving an outlet temperature of 950°C.
- The reactor is well suited for the co-generation of process heat and electricity and for the production of hydrogen from water for industrial applications in the chemical and petrochemical sectors.



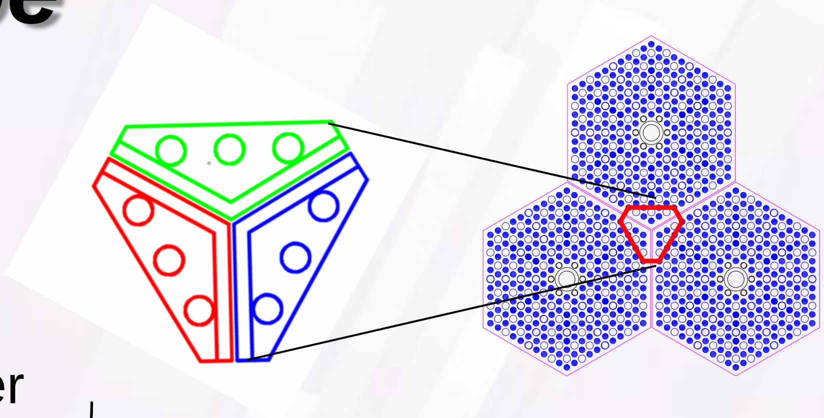
Workscope

- Technical Workscope in FY12
  - Fuels Qualification
  - Material Qualification (graphite, SiC, high temperature alloys)
  - Design and analysis methods
  - Energy transport, conversion, and application

- Proposals being sought in the areas of
  - Computational Methods and Experimental Validation (NGNP-1)
  - Heat Transport, Energy Conversion, Hydrogen Production, and Nuclear Heat Applications (NGNP-2)
  - *No fuels and materials* proposals are being solicited in FY12 (awaiting further progress on existing projects)

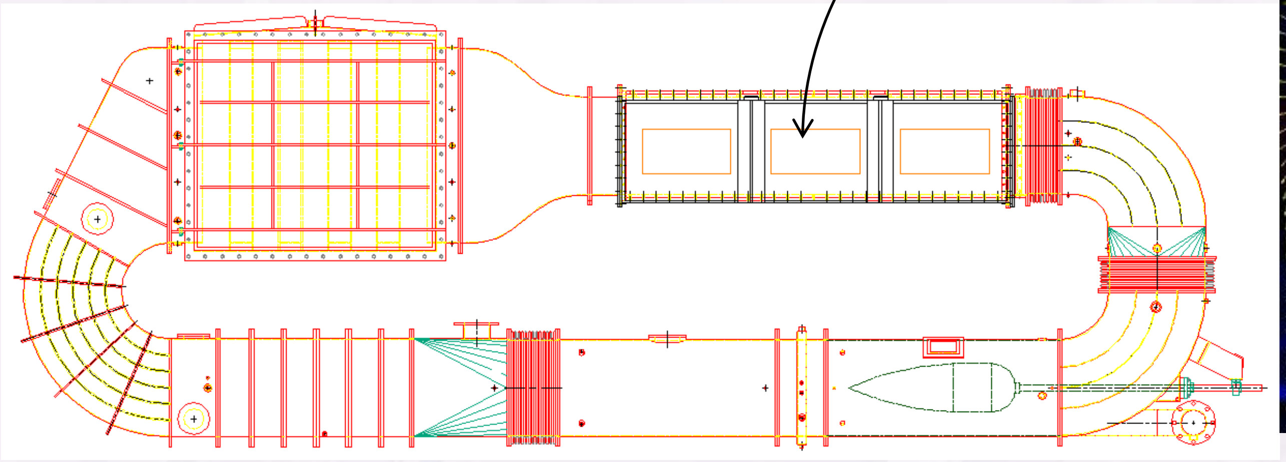
NGNP Methods Scope

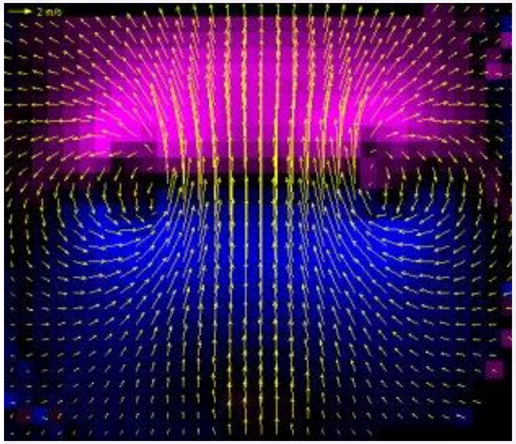
- Assessment and validation of tools for core neutronics, thermal fluids, and fission product transport
- Uncertainty Analysis
- Verification of existing tools using higher fidelity, higher order, multiphysics techniques
- Experimental validation of thermal fluid phenomena



Interstitial Block Flow Model to be inserted into the MIR Flow Loop

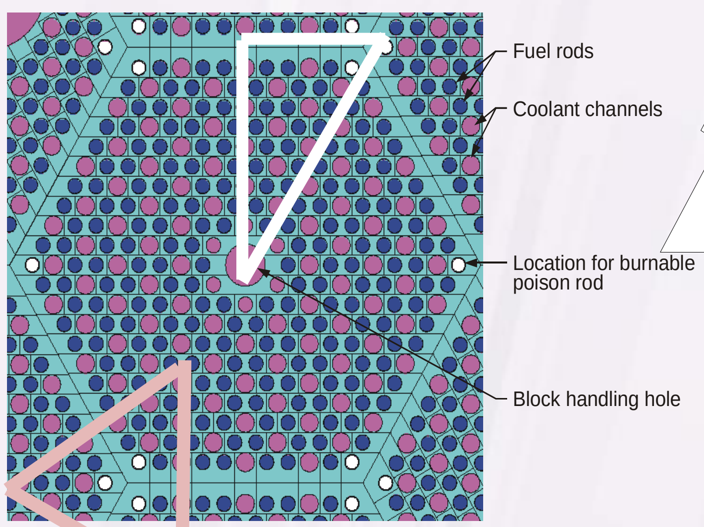
Flow field captured with Particle Image Velocimetry

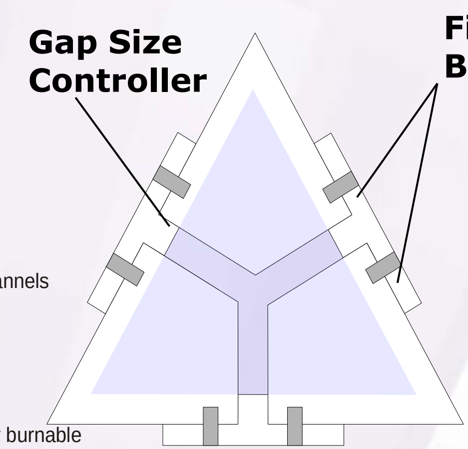


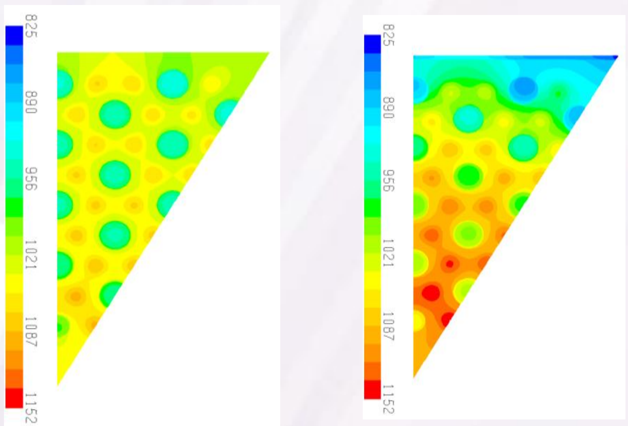


Emphasis- experimental validation

- Low Reynolds number phenomena (natural circulation sfter a circulator trip)
- Exchange flow (air-helium) after a pipe break and graphite oxidation
- Water ingress – fluid and chemical behavior
- Hot streaking into lower plenum, through coolant duct, and into turbine/IHX
- Bypass flow







No inter-block gap 3mm inter-block gap

Temperature map

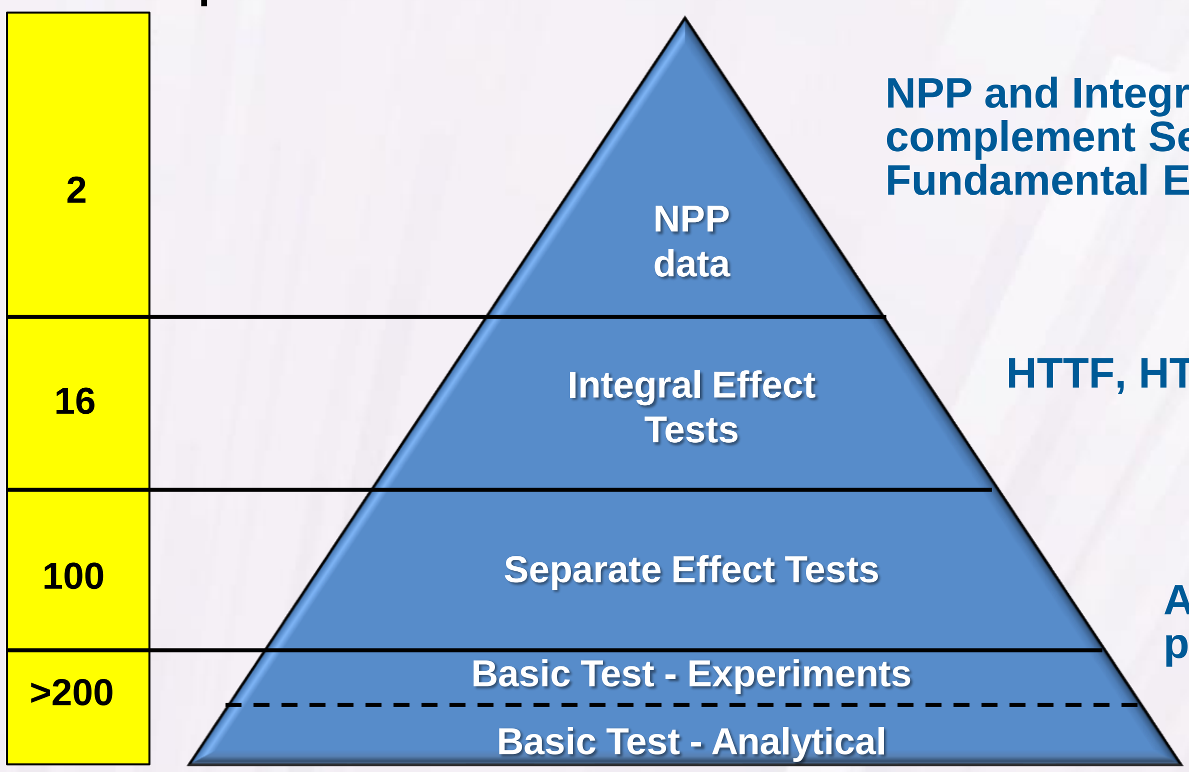
Experimental Thermal Fluid Investigations

- In the area of experiment planning and decomposition of accident scenarios into fundamental phenomena, proposals are sought that cover scaling, experimental design, fundamental phenomena identification, costing and PIRT review for one or more of the following:
  - *High Temperature Test Facility (supporting experiments)*
  - *Natural circulation in the core (plenum-to-plenum)*
  - ***Water ingress flow and chemistry***
  - *Core and boundary heat transfer experiment and multi-scale modeling*
  - *Ex-core cooling (reactor cavity cooling)*
  - *Lower plenum and bypass flow (esp. Non-isothermal)*
  - ***Leak Flow into the building from the primary***

Validation Triangle

Number of Tests

- Limited Scope



NPP and Integral Experiments complement Separate Effects and Fundamental Experiments

HTTF, HTTR, NSTF

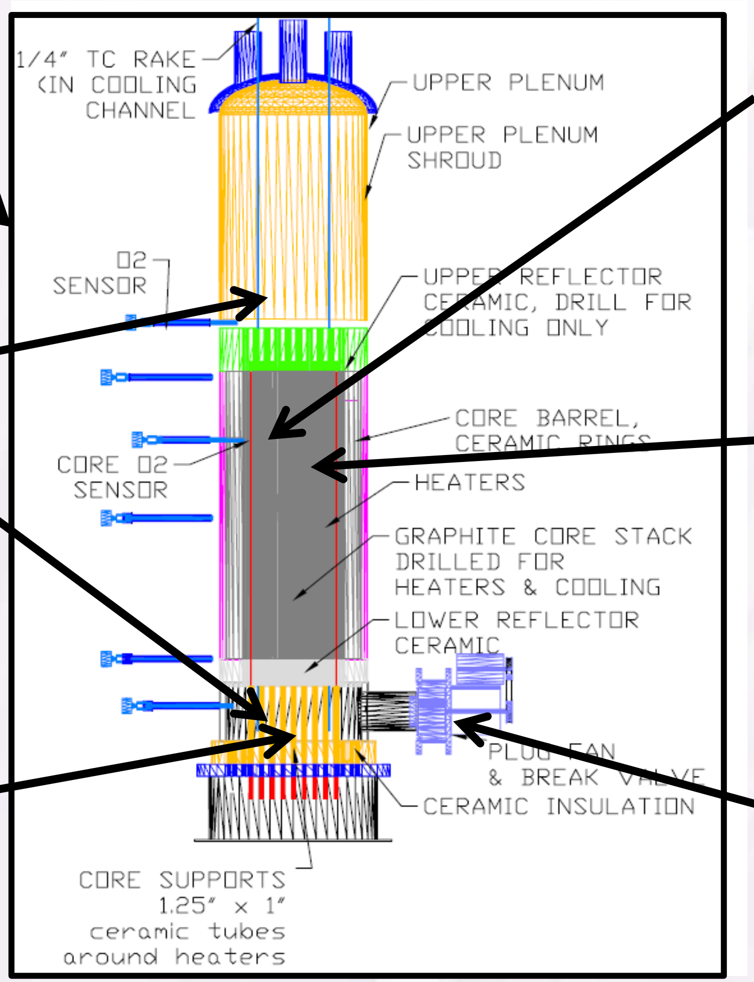
Avenue for university participation (NEUP)

Relationship of Separate-Effects Experiments to Integral Experiment

RCCS

Plenum-to-plenum

Lower Plenum Experiment



Core Heat Transfer Exp

Bypass Flow

Ingress Experiments

High Temperature Test Facility at Oregon State

Experimental Investigation of Leak Flows (post-break)

- ***Pressurization of the confinement.***
  - *If the leak is sufficiently large, confinement overpressure causes "blow-out" panels to open—allowing confinement gases to flow into adjacent compartments of the building.*
  - *If the leak is substantial enough, then the majority of the air originally in the confinement will be driven out off the confinement into the adjacent compartments—such that the confinement will be filled principally with helium.*
  - *However, as the leakage flow decreases the air "driven" out of the confinement will return to the confinement from adjacent compartments via stratified flow through the blowout panel passages.*
- ***The above scenario appears to mitigate air ingress into the reactor vessel for a depressurized conduction cooldown—for a certain class of leak sizes.***

Leak Flow (cont.)

R&D is needed to clarify the implications of this scenario. For example the following questions need to be addressed:

- *What leak sizes will initiate the above scenario and how effectively will the confinement pressurization "drive" the confinement air into adjacent compartments?*
- *What conditions will initiate the stratified flow of air back into the confinement from adjacent compartments?*
- *What variables govern the helium/air exchange between the confinement and its adjacent compartments? Define the methodology for determining the helium/air mixture fraction as a function of time, leak size, and confinement geometry*
- *What are the key factors that govern the quantity of air and the air/helium mixture fraction at the leakage site on the reactor vessel as a function of time and geometry?*

Fission Product Transport*

- Scope
  - Validation and simulation of dust generation models (wear, chemical)
  - Electrostatic interactions between dust and FP – models and validation
  - Fluid behavior of FP and dust in primary circuit and building
  - Mechanistic Determination of FP/Dust Shape Factors and breakup.
  - Generation of adsorption isotherms
  - Dust/FP resuspension

**Humrickhouse, P, HTGR Dust Safety Issues and Needs for Research and Development, INL EXT-11-21097.*

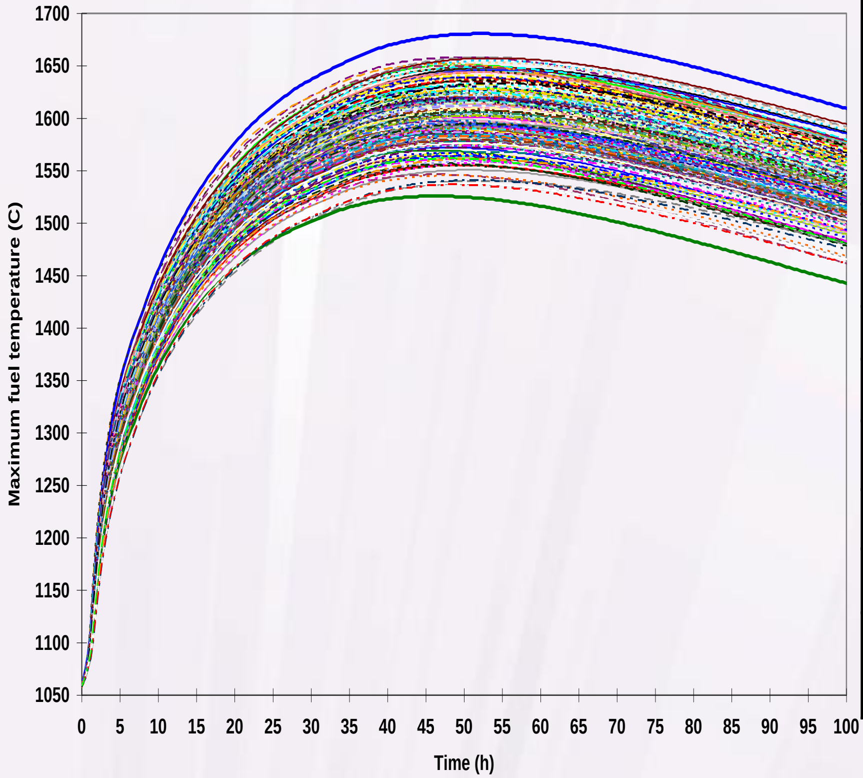
Grand Challenges

- Acquisition of high quality data for CFD and System Analysis
  - The safety and performance of high temperature reactors is a function of the helium behavior during operation and off-normal events
  - Computational Fluid Dynamics (CFD) can provide many answer but they have not been qualified for this application
  - An integrated matrix of integral and separate effects experiments is needed to validate codes and instill confidence in their results.

Grand Challenges

- Holistic sensitivity and uncertainty analysis
  - Systematic identification, characterization, and ranking of uncertainties in fuel performance, neutronics, thermal-fluids, and fission product behavior and their effects upon key safety parameters
- Multiphysics analysis of interaction between graphite structures, radiation, temperature, and fluid flow

Example: PBMR400 Peak Fuel temperature after a loss of coolant



Parameter	Variation (2σ)	Rank Correlation Coefficient
Reactor power	400 ±8 MW (2%)	0.2
Reactor inlet gas temperature	500 ±10°C (2%)	0.02
Decay heat	BE ±0.057 (5.7%)	0.6
Fuel specific heat	BE ±0.06 (6%)	-0.1
Reflector specific heat	BE ±0.10 (10%)	-0.1
Fuel conductivity	BE ±0.14 (14%)	-0.05
Reflector conductivity	BE ±0.10 (8%)	-0.3
Pebble bed effective conductivity	BE ±0.08 (10%)	-0.25

Peak fuel temperature (^{o}C) after a depressurized loss of forced cooling in the PBMR-400 (141^{o} spread)

Summary of NGNP Solicitation

- Thermal fluid experimental validation
- Dust and fission product transport
- Multiphysics simulation of complex phenomena and uncertainty analysis

Hans.Gougar@inl.gov